Shipboard Coatings Developments, and Emerging Surface Technologies

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

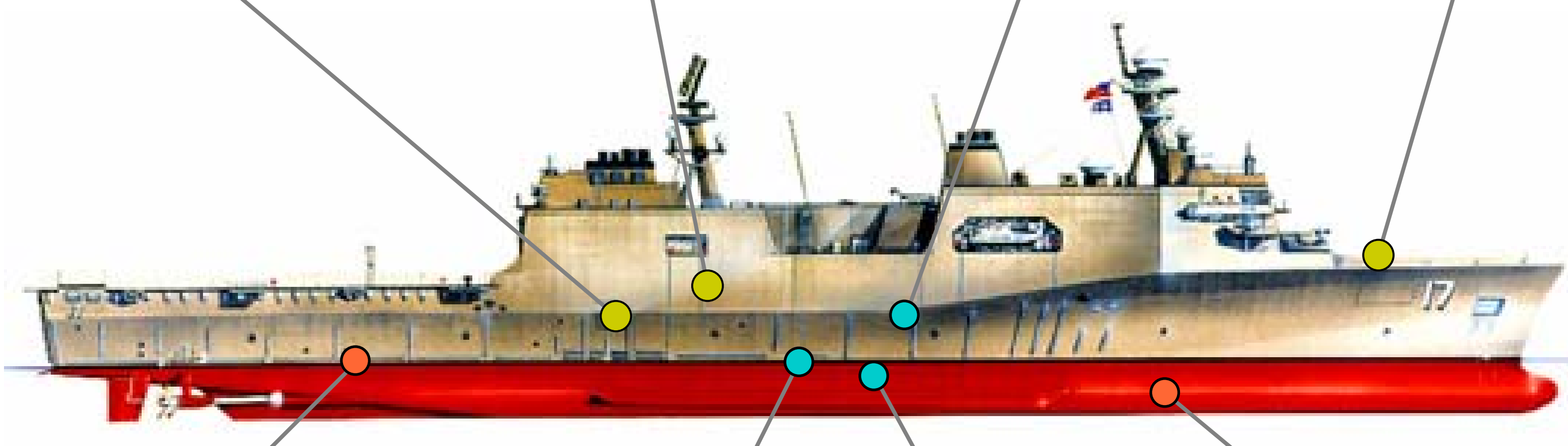
Shipboard Coatings

Topside Coatings
Polyesters
Silicone-Alkyds
Polyurethanes
LSA/Antistain

Special Treatments
Nitriles
Urethanes

Interior Coatings
Chlorinated Alkyds
Chlorinated Vinyls
Polyimides

Deck Coatings
Acrylic Epoxies
Polyurethanes
Polysulfides



Anti Corrosion Coatings
Epoxy-Polyamides
Epoxy-Amines
Epoxy-Amidoamines

Tank Coatings
Epoxy-Polyamides
Novolac Epoxies
Solvent Free
Edge Retentive

Bilge Coatings
Epoxy-Amidoamines
Epoxy-Polyamides

Voids
Inorganic Zinc
Zinc Rich Epoxy

Anti Foulant Coatings
Vinyls
Silicones
Fluoroelastomers

Single Coat Preservation System
Portsmouth Naval Shipyard / SEA 05P23

- Application of rapid-cure, high-solids paints in a single-coat is more cost effective than applying paints in two or three discrete steps.

PROBLEM: Ultra-high-solids coatings require three coats (i.e., primer, stripe coat, and top coat) = Excessive Labor. Legacy coatings require 24-hours between coats and seven days before service, for total process time of >14 days.

SOLUTION: Single-coat system based on application of a single color of paint, during a single coating evolution in the tank, with multiple passes of the paint gun. Cure time only four hours at 77F and one day to service.

CWP reports savings of up to 20% possible for CVN ($433K) availability.

Contactors report job cost savings of 26% possible.

<u>Accomplishments:</u>

1. Change 1 to FY-10, Standard Item 009-32, allowing only use of single-coat paints in ballast tanks, voids, and chain lockers issued on 9 March 2009.
2. Completed single-coat ballast tank/void installations on carriers, submarines, amphibious ships and combatant tanks/spaces.
3. Completed demonstration installation of single-coat paints in three fuel and two CHT tanks.
4. Completed one-year inspection of single-coat paints in ballast tanks on submarines and amphibious ships.

Single-coat Performing “As Advertised” & Preventing Tank Corrosion.

BUSINESS CASE FOR SINGLE COAT PAINTS
Cost Estimate Summary

- Cost estimates based data from shipyards, contractors, and paint vendors. Costs estimates are for painting a "representative" 5,000 ft^2 tank and do not include consistent costs like cleaning, staging set-up, blasting, and clean-up. NAVSEA business case consistent with:

Cumbersome work practices, single-coat project	20% paint application cost reduction after CWP demonstration
	$433K possible savings DPIA.
Contractor reports savings:	15% to 30%

MODEL RESULTS:

- Single-coat paint total application costs <u>lower</u> than other coating systems.

Solvent-based paints (MIL-PRF-23236, V or MIL-DTL-24441) 15 mils DFT	$31,128 to $30,888	
100% Solids paints at 17 mils DFT	$24,833	}22% reduction
100% Solids, single-coat paints at 25 mils DFT	$19,250	

- Single-coat paint material costs <u>higher</u> for 5,000 square foot tank.

Solvent-based paints	$1,296 to $1,056
100% Solids paints	$2,898
100% Solids, single-coat paints	$6,292

- Facilities & utilities costs <u>lower</u> for single-coat paints.

Solvent-based paints	$13,100
100% Solids paints	$8,300
100% Solids, single-coat paints	$7,300

- Labor for single-coat paint <u>lower</u> than other paints.

Solvent-based paints	$16,732
100% Solids paints	$13,635
100% Solids, single-coat paints	$5,658

Induction Heating Coating Removal
Portsmouth Naval Shipyard / SEA 05P23

Issue:

Current methods of coatings removal require media (e.g., mineral grit, shot, water, etc.), or cumbersome hand tools.

Problem: Removal of thick, tough paints takes too much time.

Solution: Use the Induction Heating (IH) Coatings Removal system to “pop” paint up from heated substrate, no need to wear paint away.

Accomplishments:

- **NAVSEA ltr Ser 5000 - 07T/0226 dtd 3 July 07 provided interim approval to PNSY, with conditional requirements addressing substrates, controls, etc.**
- **Uniform Industrial Process Instruction (UIPI) 1905-115 signed on 31 July 2008.**
- **Each Naval shipyard has at least one induction heat unit. Qualification in process at all yards.**
- **Units used to remove rubber in battery boxes on submarine in April 2009.**

PSNY projects, potential cost reduction:

Submarine - $93K / availability.

Carrier - $57K / availability.

Development of Automatic Control Head Key to Expand Applications for Units

ANTIFOULING COATING PROGRAM
Overall Goals

- **Navy needs to control underwater-hull fouling using environmentally acceptable methods.**
  Fouling control is important to allow Navy ships to:
  - **Attain critical speed – 2% speed loss.**
  - **Reduce noise.**
  - **Minimize operating expenses:**
    - **6% to 45% increase in fuel cost ($910K/year per DDG).**
    - **$22M to $44M spent annually on underwater-hull coating & diver cleanings.**
  - **Last for up to 12-years with no docking or touch-up.**

- **NAVSEA goal is to adopt new, advanced coating systems for fleet-wide implementation.**
  - **Current Navy fleet underwater-hull area, 99% coated with copper ablative – 12,434,472 ft^2 or 1,155,200 m^2**
  - **Foul-release coatings on 26,635 ft^2 or 2,660 m^2**

Effective, copper-free or foul-release will become new Navy standard.

ANTIFOULING COATING PROGRAM
Environmental Drivers Of Change

- **World-wide antifouling coating environmental regulations are changing:**
  - **International Maritime Organization (IMO) tributyl tin (TBT) ban to come into force on 17 Sept. 2008 – TBT paints are banned.**
  - **Canada, 40 ug/cm^2/day limit on copper emissions from antifouling paints.**
  - **Sweden has copper emissions limits on antifouling coatings in Baltic, 200 ug/cm^2/14-day.**
  - **Netherlands bans cleaning or scrubbing of copper-bearing antifouling.**

INTERNATIONAL PRECEDENTS ESTABLISHED FOR BIOCIDE & Cu REGULATION

- **Local water-quality issues in ports with military & civilian ships leading to new domestic regulations.**
  - **San Diego violates federal water quality standards – California evaluating new regulations. San Diego Regional Water Quality Board issued a 20-year plan to phase out copper-bearing paints (San Diego, *Times Union*, 28 April 2005), so phase out in 2025.**
  - **Puget Sound Naval Shipyard (PSNS) has had NOVs for copper discharge from drydocks.**
  - **Hull-coating leachate is identified UNDS discharge.**

NUMERICAL UNDS COPPER EMISSION LIMIT TO BE PROPOSED IN 2009.

"NEW" COATING MUST SATISFY CURRENT & FUTURE ENVIRONMENTAL REQUIREMENTS

ANTIFOULING COATING PROGRAM
Program Approach

ENVIRONMENTAL & PERFORMANCE GOALS

OPTION 1: NON-COPPER
- DEVELOPMENTAL COATINGS.
- NOT EPA REGISTERED.
- SHORT HALF-LIFE (e.g., 10-hour) BIOCIDES.

MIL-PRF-24647D category

Two products failed ship test,

OPTION 2: LOW-COPPER CO-BIOCIDE COATING
- COMMERCIAL PRODUCTS
- SOME CO-BIOCIDES, NOT EPA REGISTERED.
- SHORT HALF-LIFE (e.g., 10-hour) BIOCIDES.

BEST OPTION 2 PRODUCTS

Don't currently meet Navy needs.

No product of interest under testing

OPTION 3: FOUL-RELEASE NON-TOXIC COATINGS
- COMMERCIAL COATINGS.
- NAVSEA SPECIFICATION REVISION IN PROGRESS.
- TEST INSTALLATIONS ON MCM-1 & MCM-14.

MIL-PRF-24647D INCLUDES CATEGORY.

International Intersleek 425 included on MIL-PRF-24647D Qualified Products List

International Intersleek 900 started ship trials.

ANTIFOULING COATING PATCH TESTING
USCG MLB 47256 with Copper-free Coating

ANTIFOULING SYSTEM: Copper-free product, ablative matrix,

TEST SYSTEM APPLIED: January 9 - 22, 2005

LOCATION OF WORK: USCG STATION, SAN JUAN, PR

INSPECTED: Aug. 2005 LIGHT ALGAE GROWTH.

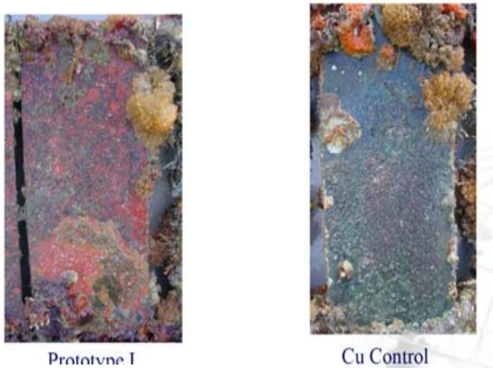
Other pulls not recorded, no complaints to NAVSEA about speed.

April 2008 Pulled for engine work, cleaned well, may have been over-coated.

PRESSURE WASH, ALGAE EASILY REMOVED, POLISHING APPARENT.

SOME HARD FOULING ON WELDS, NOT A SPEED PROBLEM, BOAT CREWS WANT MORE MATERIAL.

BATELLE TEST SITE, 58 MONTH, FULL IMMERSION RESULTS

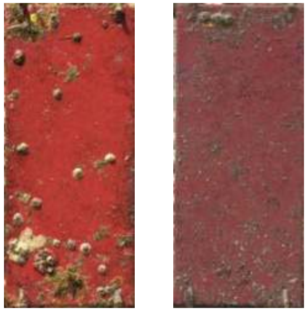


Option 1 **Cu Control**

OPTION 1 SHIP TEST
Full ship Test of Option 1 Failed in 2006

Antifouling test system: red top coat of option 1 over Cu ablative. EPA EUP granted in Nov. 2004 for USCG KNIGHT ISLAND (WPB-1348) based in Tampa, FL.

Test system application: February, 2005
Master Marine – Bayou LaBatre, LA



Option 1 / ablative full-immersion panels, 18 months Biscayne Bay, FL

Inspected: June 2005, & April 2006

- **Soft fouling & hard fouling apparent.**
  USCG had speed problems.
- **Hull only cleaned with abrasive pads.**
- **Option 1 not as good as Cu ablative.**

Cu-ablative

Option 1

Cu Ablative

Option 1

Emerging Surface Technologies: Low-Temperature Colossal SuperSaturation (LTCSS) Surface Hardening on Alloy A286

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Background: LTCSS Process

Traditional Carburization

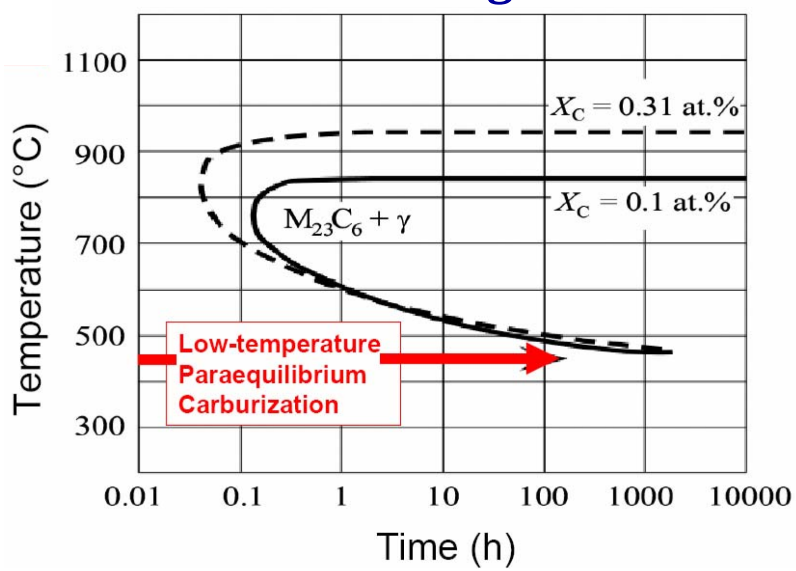
- Traditional carburization is a thermochemical surface treatment that is commonly used to increase the hardness and wear properties of steels
- Traditional carburization requires temperatures around 950°C, and in austenitic stainless steels this results in the formation of chromium carbides ($Cr_{23}C_6$) which significantly degrade corrosion resistance.

LTCSS Surface Modification

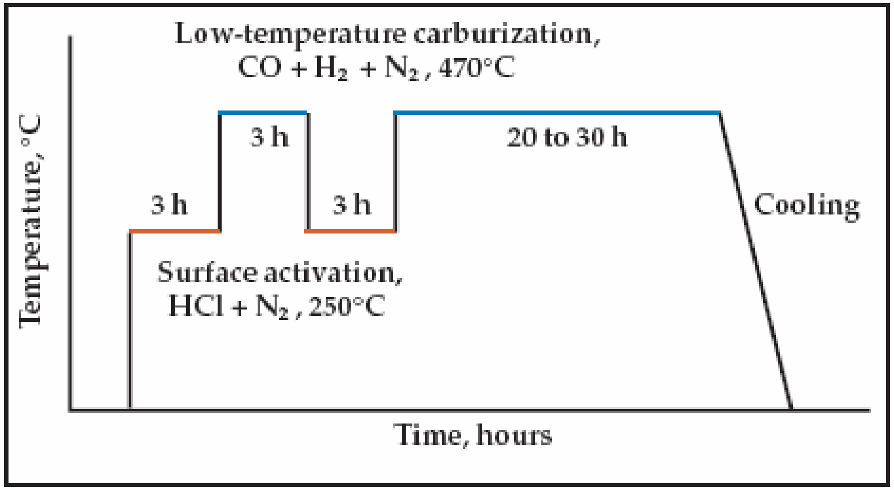
- Carbon concentrations > 12 at. % in 316 stainless steel while maintaining single phase austenite, i.e.. no detrimental precipitates.
- Treatment temperatures below 570°C
- Significant increases in surface hardness, wear and corrosion resistance.

Ref: G. M. Michal, et al., Acta Materialia 54, 1597 (2006).

TTT diagram



LTC Treatment Conditions

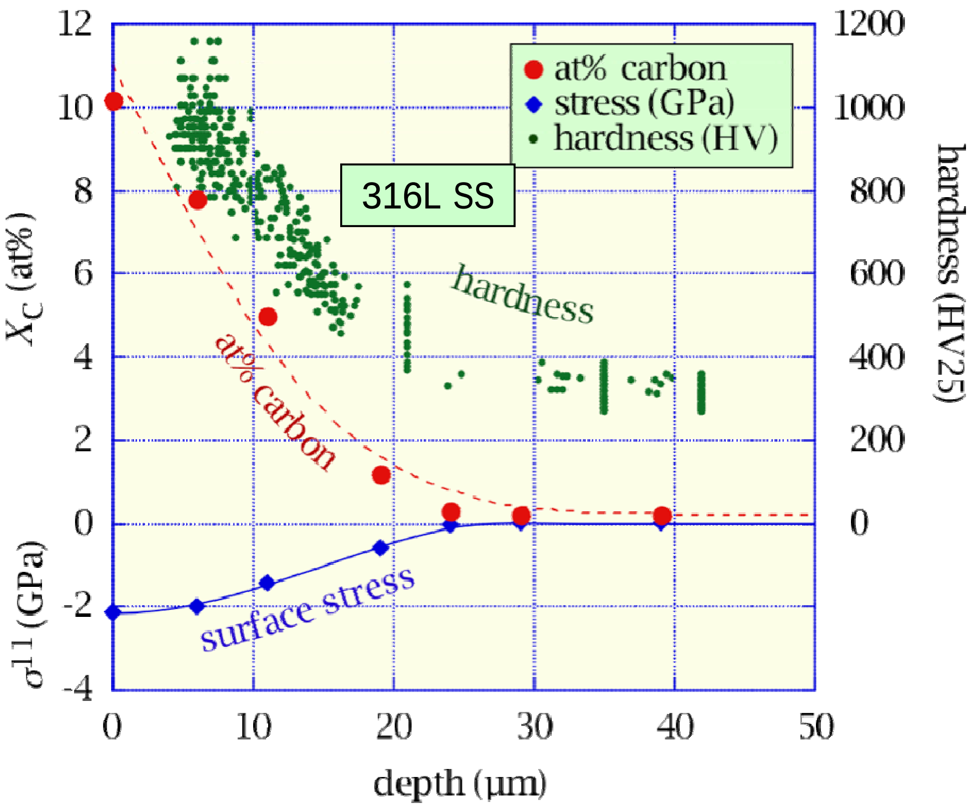


Correlation Between Carbon, Hardness and Surface Stress

- **As much as 10-12 at% carbon is incorporated into grain structure near surface**
- **There is a significant surface compressive stress (~2GPa) imparted by interstitial C**
- **Austenite** surface hardness is tripled **by treatment. 316L attains Vickers 1100 (Rockwell 70C).**

316L SS (UNS N31603)
Before treatment

Element	at%
Fe	64.94
Cr	18.45
Ni	11.62
Mn	1.79
Mo	1.19
Si	1.18
C	0.23

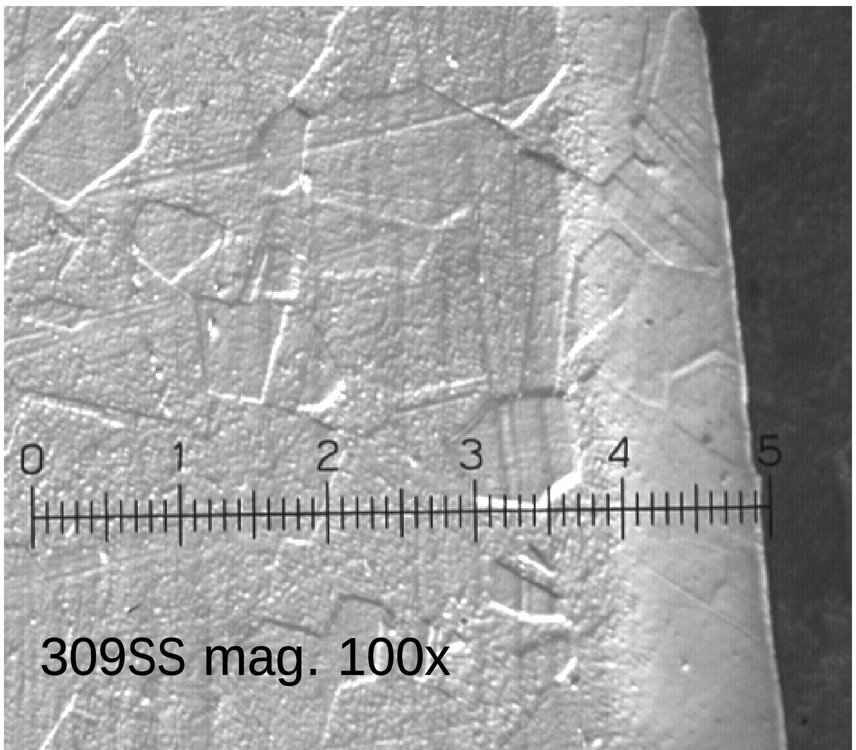


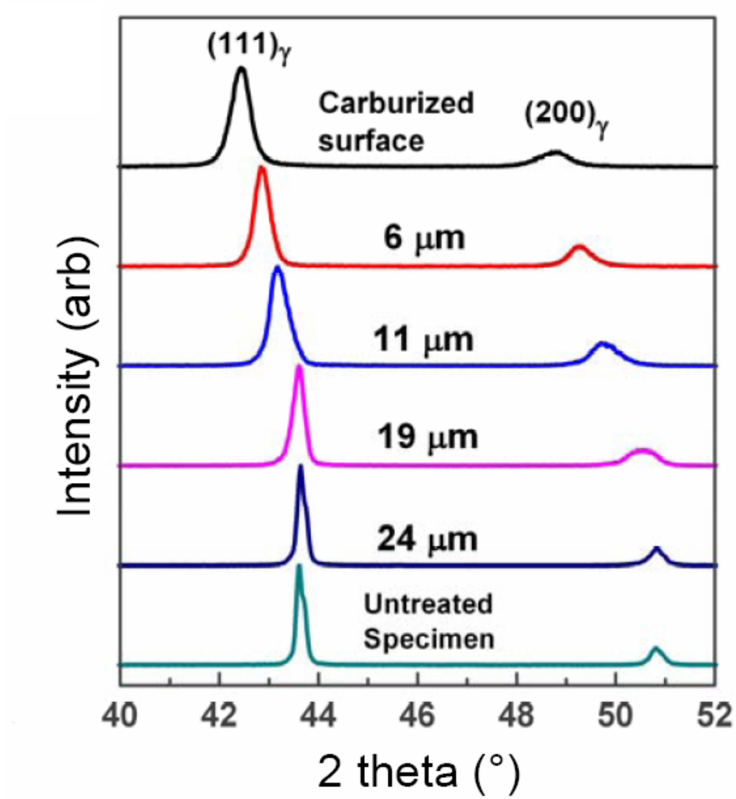
Ref: G. M. Michal, et al., Acta Materialia 54, 1597 (2006).

LTCSS Microstructure

- **Original grain structures retained with significant interstitial carbon**
- To date, no precipitates or carbides observed in 316L SS **– carbon is interstitial with significant lattice expansion indicating residual compressive surface stress**
- **Interstitially carburized layer is referred to as "S-phase"**

XRD on 316SS





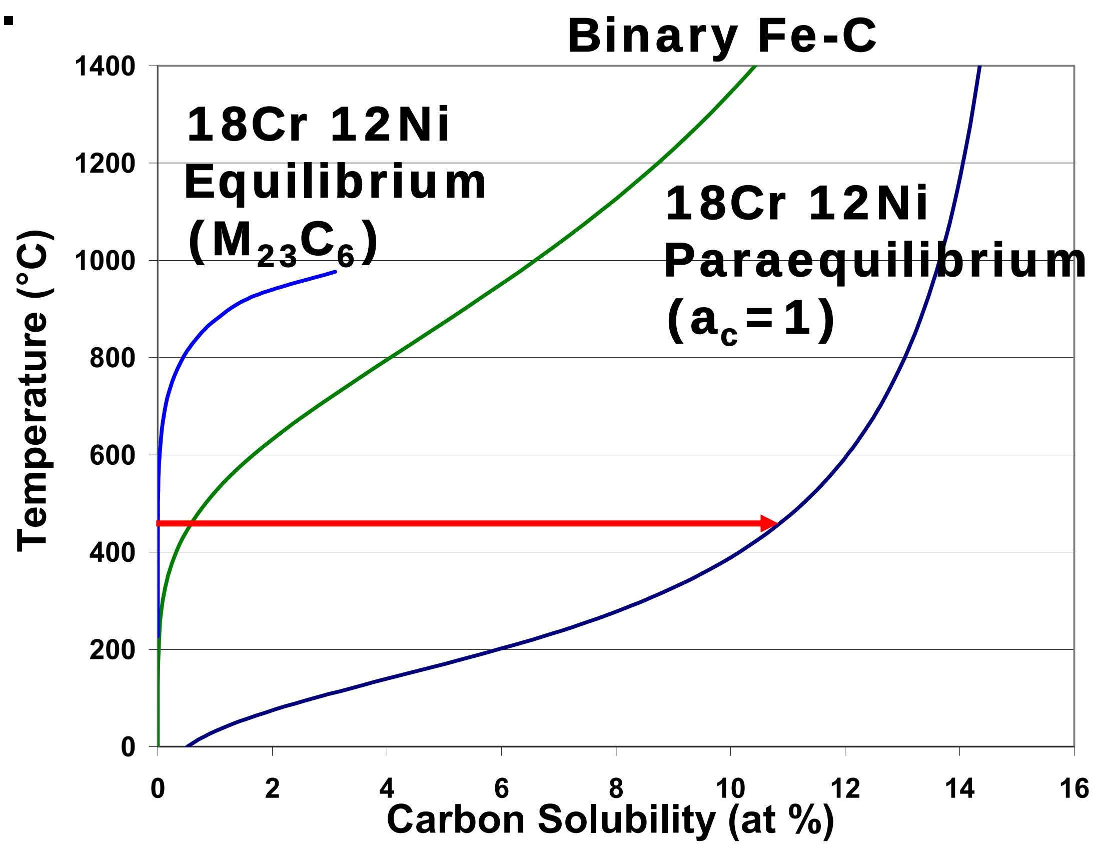
Ref: G. M. Michal, et al., Acta Materialia 54, 1597 (2006).

Low-Temperature Carburization

- **LTCSS is <u>one approach</u> to low-temperature carburization. It occurs in a gas chamber at elevated temperatures. Temperatures are lower than conventional carburization.**
- **In order for chromium carbides to form in a stainless steel, BOTH the metal atoms AND carbon atoms must be mobile enough to form new compounds.**
- **Low-temperature carburization is hot enough to allow diffusion of carbon into metal lattice interstices, but cool enough that metal atoms are kinetically restricted from classic carbide recombinations to form precipitates.**
- ***Para-equilibrium* carbon diffusion can absorb MUCH more carbon into the metal host than normal diffusion processes.**

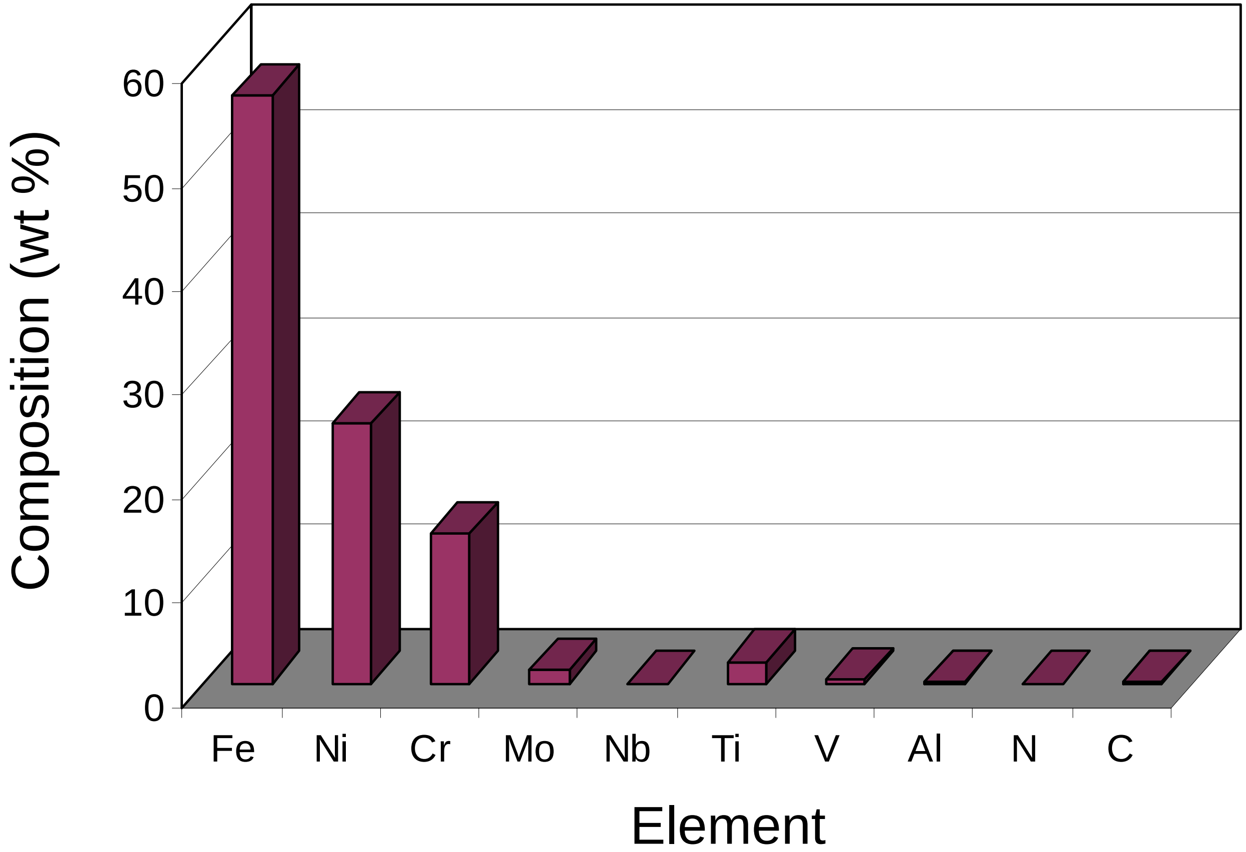
How are high carbon concentrations possible?

- **Saturation limits for equilibrium and para-equilibrium carbon diffusion in stainless steel. At 450C, equilibrium-based diffusion allows about 0.1%C into stainless steel while *para-equilibrium* diffusion supports up to 11% carbon (or more).**



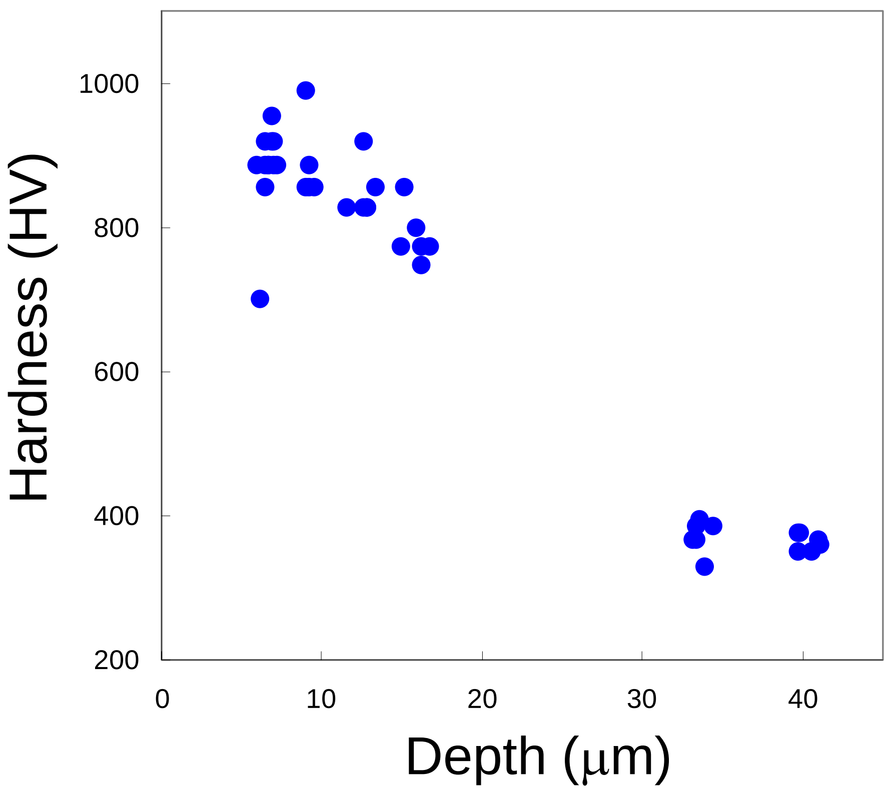
Alloy A286 Composition

- Alloy A286 (UNS 666286) is a high strength, austenitic stainless steel, age hardenable.
- Present work uses A286 in fully aged condition

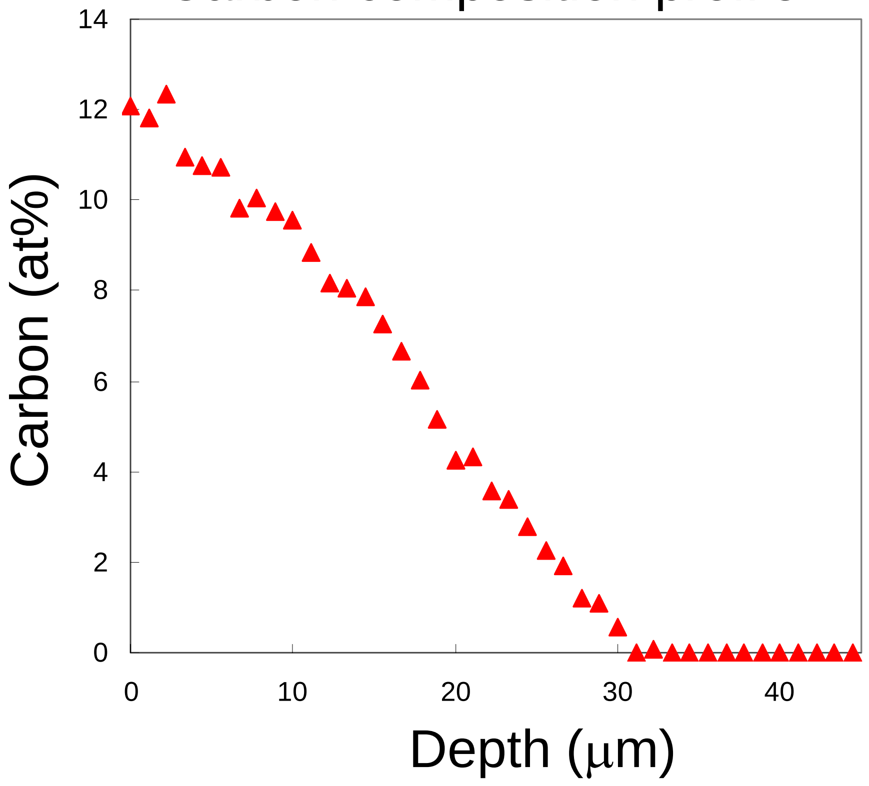


LTCSS Alloy A286 Case Depth and Carbon Profile

Microindentation –
Hardness profile



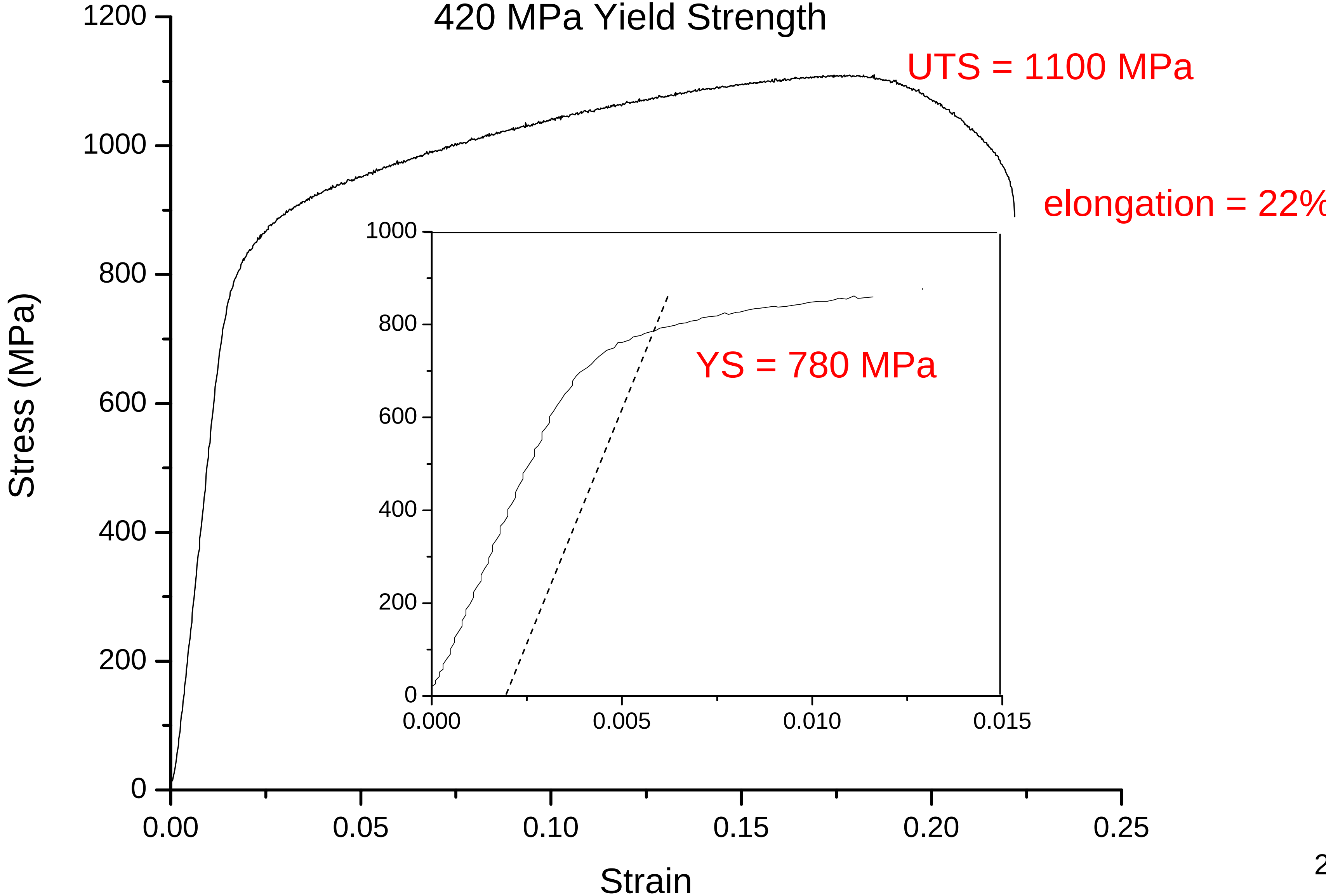
Auger electron spectroscopy –
Carbon composition profile



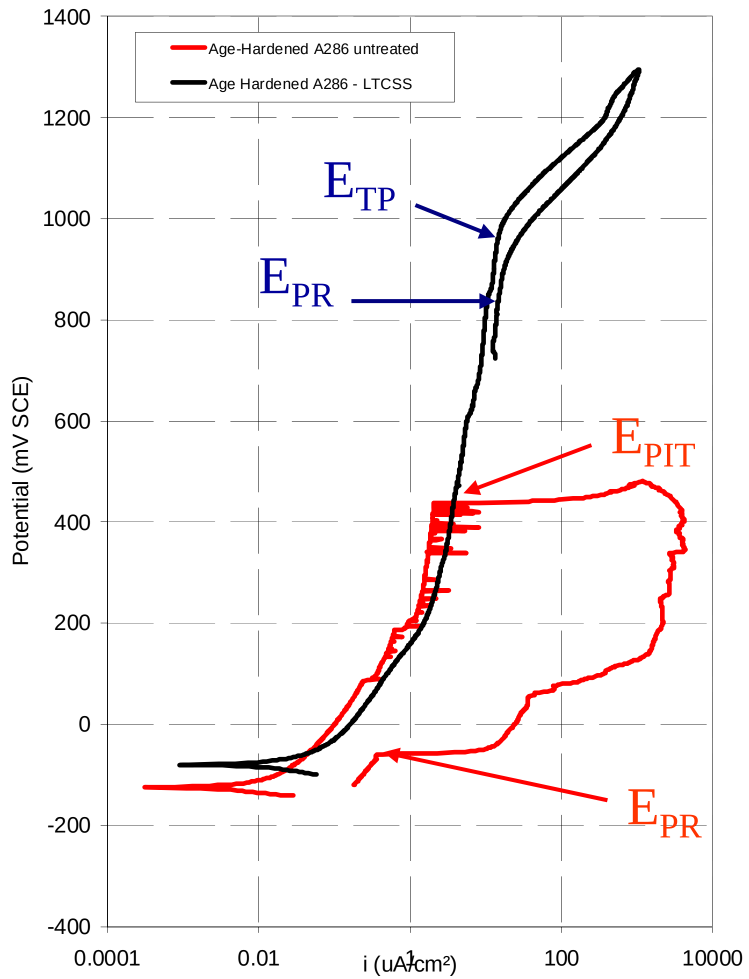
Microhardness and carbon concentration profiles
indicate 32 μm case depth

LTCSS A286 Mechanical Properties

Metric = 600 MPa Ultimate Tensile Strength, 15% Elongation at Rupture, 420 MPa Yield Strength



LTCSS Alloy A286
Pitting Corrosion Behavior

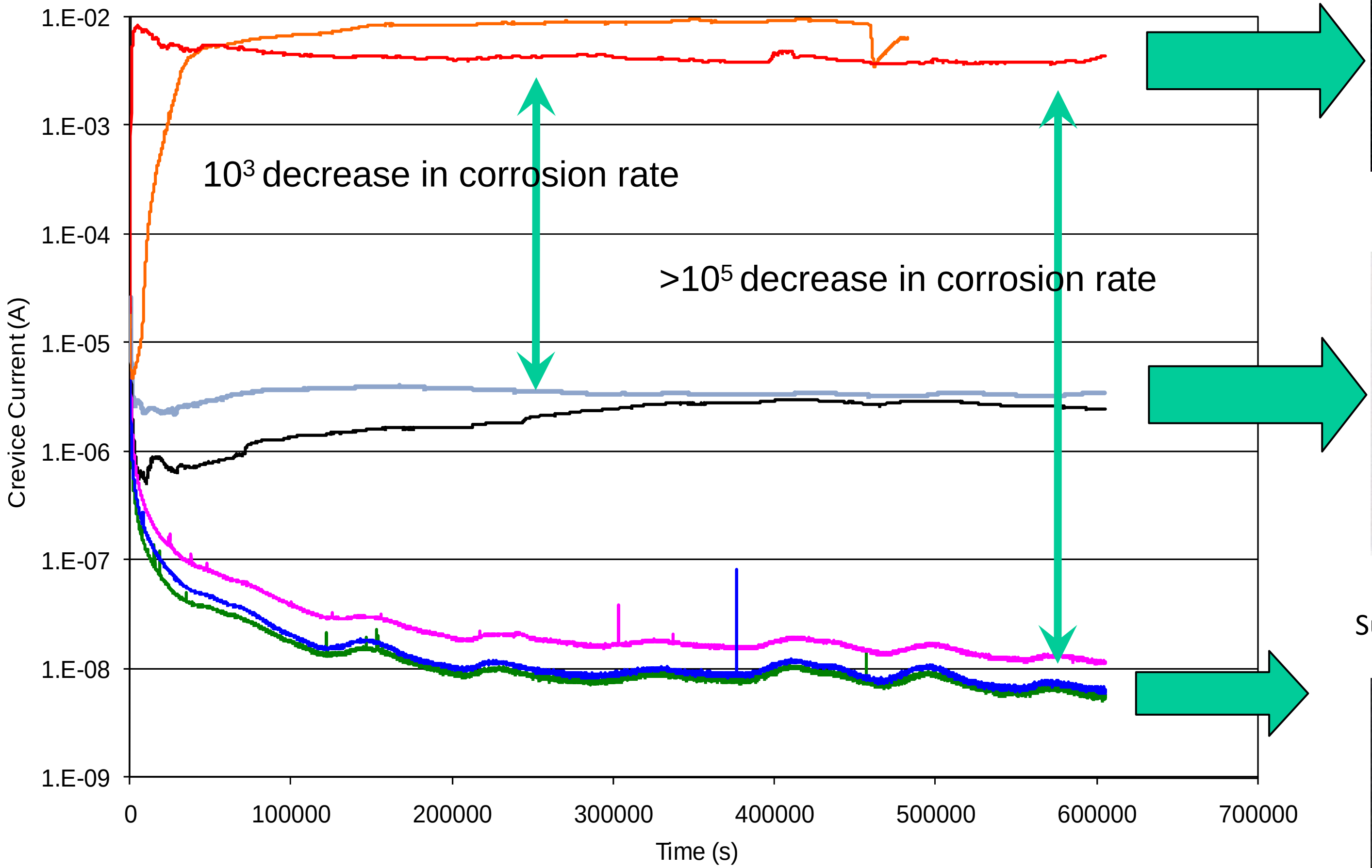


- **Unmodified Alloy A286**
  - Short-term* E_{OC} – 120mV
  - E_B +430 mV (pitting)
  - E_{PR} –100mV
- **LTCSS A286**
  - Short-term* E_{OC} – 75mV
  - E_{TP} +950 mV (transpassive)
  - E_{PR} +800 mV
- **Breakdown potential increased by ~500 mV**
- **Protection potential increased by ~1000mV**

*** Short-term E_{OC} does not take into account seawater biofilm corrosion potential ennoblement, which elevates E_{OC} to values approaching +300mV in ~30 days**

LTCSS Alloy A286
Seawater Crevice Corrosion Resistance

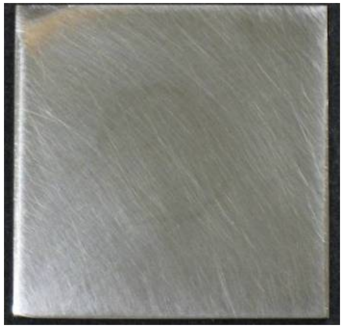
Ambient temperature seawater crevice current, potentials maintained at +300mV for one week.



Alloy A286
~100 mil crevice depth

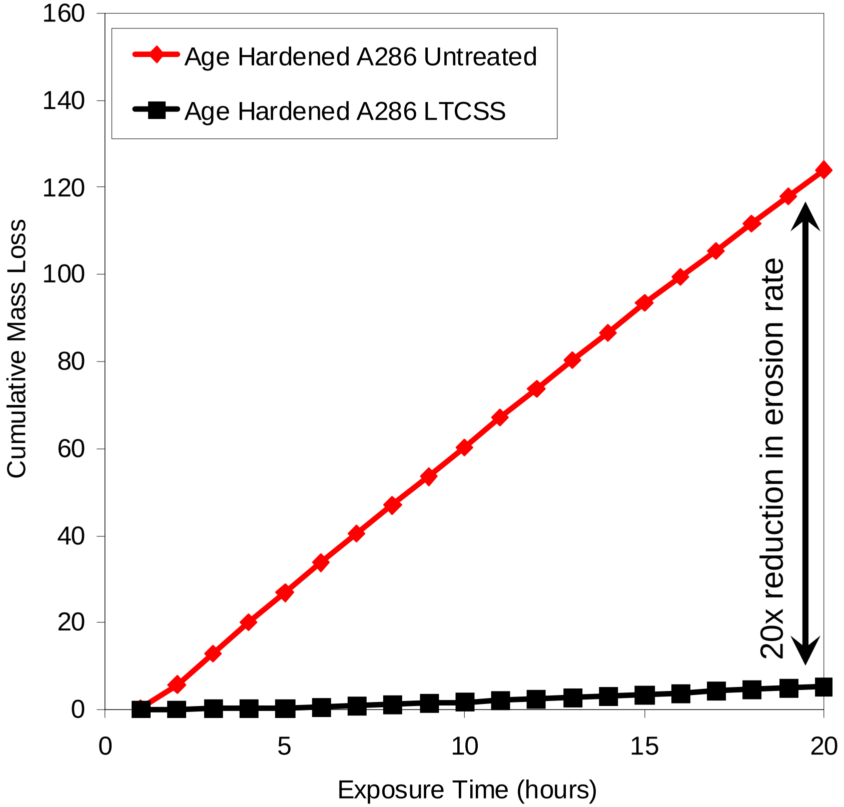
LTCSS Alloy A286
Crevice etch (< 1 mil)

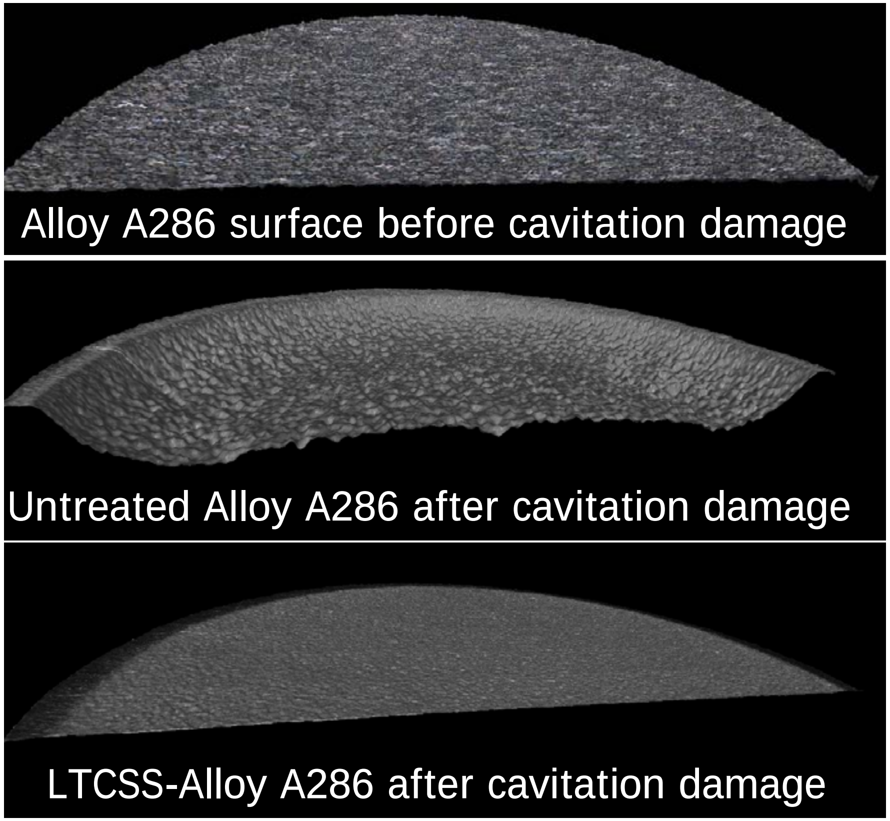
LTCSS Alloy A286
Surface Cleaned Postprocess
No attack



LTCSS Alloy A286 Cavitation Erosion Resistance

- **ASTM G32 Cavitation Erosion using ultrasonic horn at 20kHz.**
- **LTCSS-Alloy A286 erosion rate is 20 times lower than untreated Alloy A286 in ASTM G32 cavitation testing**

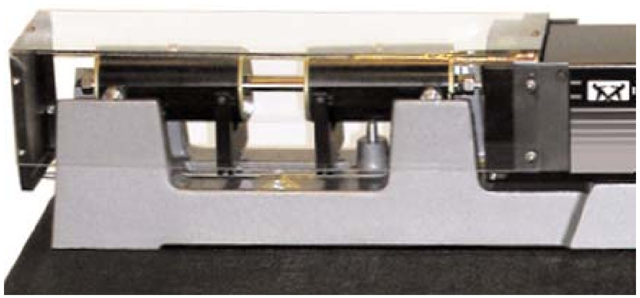


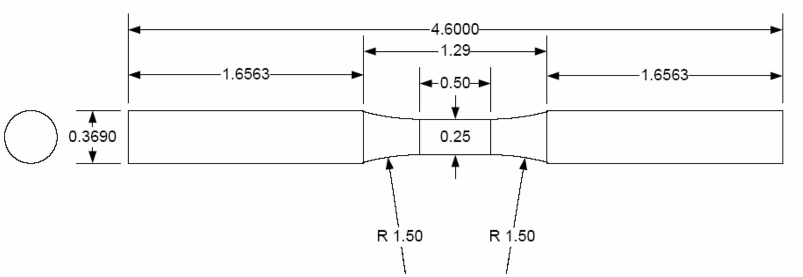


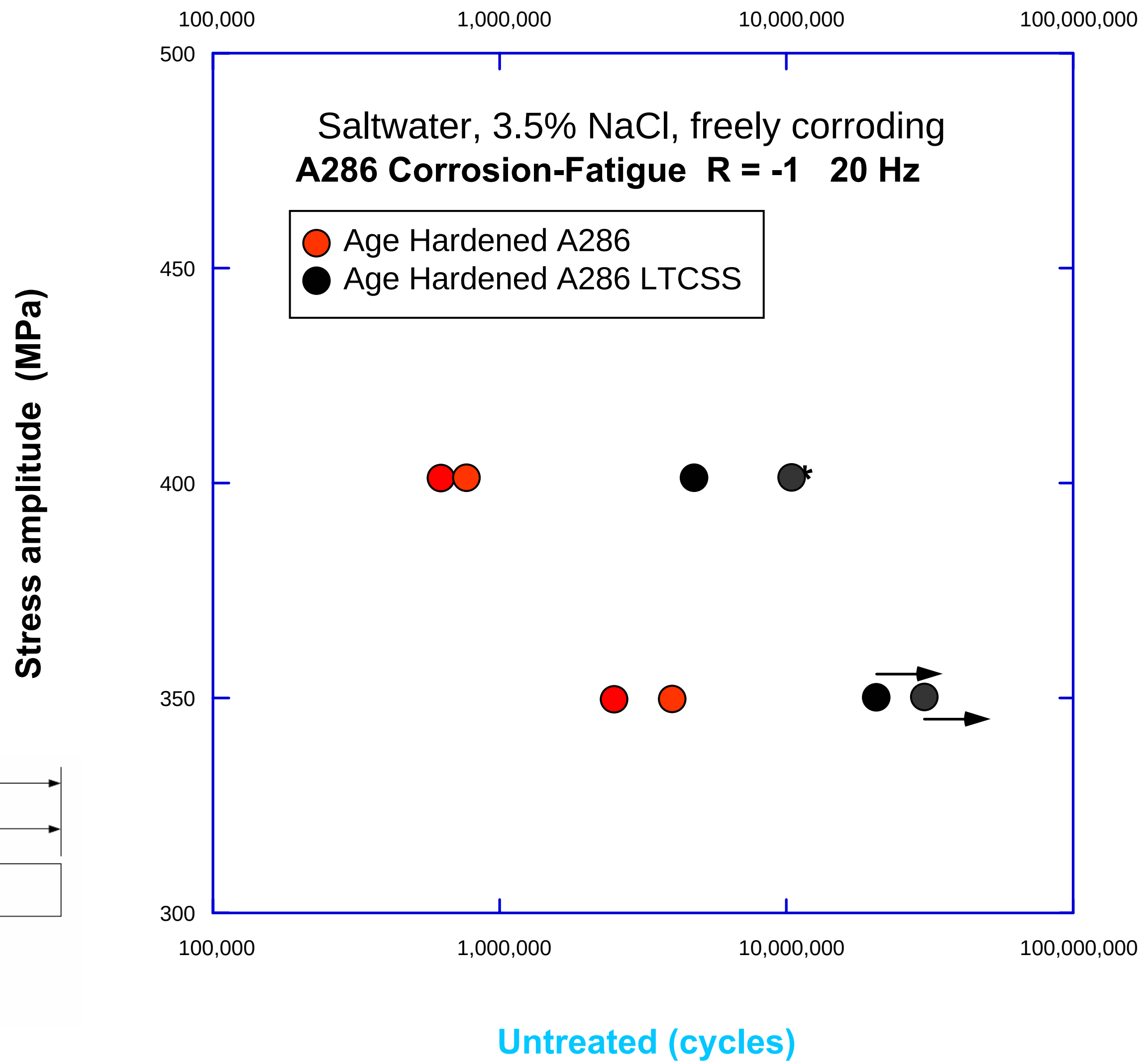
Field of view: 3D surface profile on 5/8” diameter testing coupon (10x)
20 hours exposure to ASTM G32 ultrasonic cavitation source

Corrosion Fatigue Response of LTCSS A286

- **Rotating Bending Fatigue**
- **Fully reversed loading at 20Hz**
- **Immersion cell containing 3.5% NaCl solution**
- **Smooth surface corrosion fatigue**
- **LTCSS A286 corrosion fatigue life is 10x longer than untreated alloy.**







Summary

- **Alloy A286 low-temperature carburization surface treatments have been investigated using Low-Temperature Colossal SuperSaturation method.**
- **A carburized case of about 30 microns resulted, with indications that a second metallurgical phase had developed.**
- **LTCSS modifications to Alloy A286 surface appear to increase seawater pitting and crevice corrosion resistance, increase corrosion fatigue life, and increase cavitation resistance.**
- **LTCSS-treated Alloy A286 appears not to influence hydrogen embrittlement sensitivity of the alloy.**